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This report documents a method to estimate runflat stiffness using the bulk modulus of the runflat material. For the example dimensions and material properties given, the runflat stiffness is estimated to be approximately 6,000 pounds per inch and will be contacted after 4.53 inches of tire deflection. The report describes example runflat technology and dimensions, discusses bulk modulus and appropriate values for it, details the calculation for determining compression of the runflat, describes the method used to estimate the runflat force upon impact and its stiffness rate at various tire deflections, determines the amount of tire deflection at which runflat contact begins, and summarizes the results.

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No. **16996**

By: Bylsma and Gunter

Estimating Runflat Stiffness

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Estimating Runflat Stiffness

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1.0 INTRODUCTION

This report documents an effort to calculate runflat stiffness to be used in tire models for predicting vehicle dynamic performance. Particularly in off-road environments, runflat technology plays a significant role in predicting forces impacting the vehicle chassis. An outline of the following sections is as follows: Section 2.0 Description describes the runflat technology and dimensions, Section 3.0 Rubber Properties discusses bulk modulus and appropriate values for it, Section 4.0 Compression Calculation details the calculation for determining compression of the runflat, Section 5.0 Spreadsheet Calculations describes the method used to estimate the runflat force upon impact and its stiffness rate at various tire deflections, Section 6.0 Contact Region determines the amount of tire deflection at which runflat contact begins, Section 7.0 Results combines together previous sections and provides a final result for runflat stiffness, Section 8.0 Summary summarizes the results.

2.0 DESCRIPTION

The runflat considered in this report is a Variable Function Insert (VFI) made by Hutchinson Inc. A description follows from [1]:

VFI (Variable Function Insert) - a solid rubber insert that fits securely around a multi-piece, "flat base" rim. The device is inserted into a tubeless tire, which is in turn fitted around the wheel, thus becoming an "assembly" of complimentary components all designed to work together to provide optimum mobility. Two types of wheels are satisfactory for use in this "assembly" …either a "2 piece bolt together" or a "3 piece lock ring style" which utilizes a lock ring and side ring to secure all the parts together.

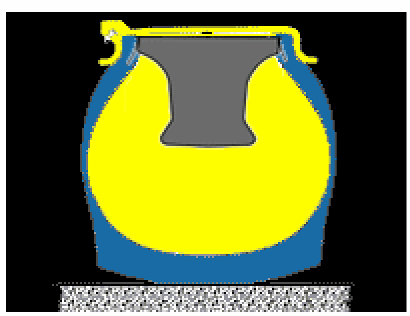

Figure 1 – Hutchinson VFI Runflat [1]

In addition, the VFI provides improved survivability for vehicle occupants due to the nature of its design and the added benefit of the dense rubber material from which the product is manufactured. The Hutchinson VFI is also designed to function as both a beadlock and runflat, thus providing maximum performance in all terrain conditions. Most importantly, the VFI meets all U.S. military standards, as well as the FINABEL and NATO standards required by most European military agencies …making the VFI the most widely used runflat in the world.

Table 1 provides dimensions for an example runflat.

Table 1 – Runflat Dimensions (inches)

Inner Radius	8.0
Outer Radius	11.9055
Width	2.6

3.0 RUBBER PROPERTIES

The stiffness of rubber is directly related to its compressibility. Bulk modulus is a measure of this compressibility as outlined in [2]. As stated in [2], “the higher the bulk modulus, the less compressible or stiffer…”. A succinct description is also given in Figure 2 below.

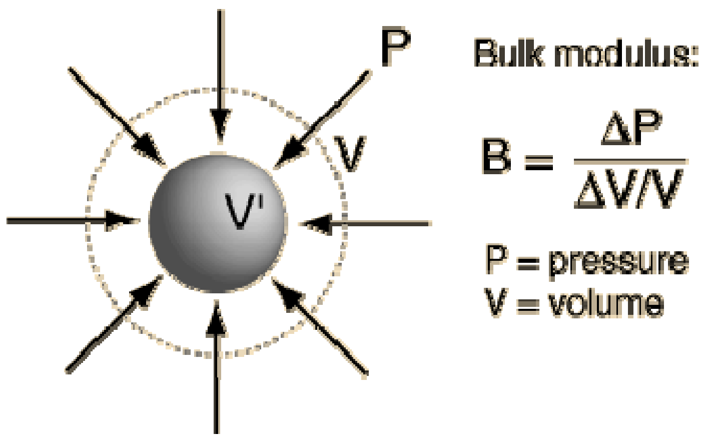

Figure 2 – Definition of Bulk Modulus [3]

Bulk modulus (MPa) will be used to estimate the rubber runflat stiffness. Based on work done in [4] as shown in Figure 3, low frequency values of bulk modulus range between 1 to 1.5 MPa.

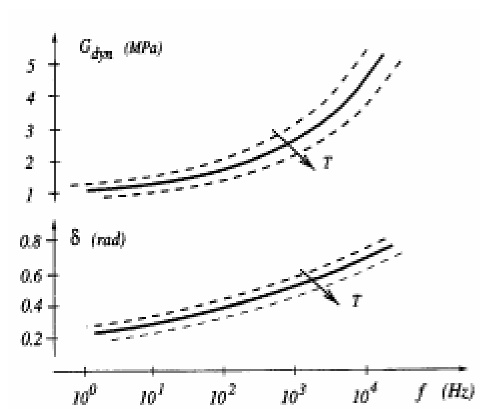

Figure 2.2. The frequency dependency of the dynamic modulus and the phase shift. (Source: Austrell [3]).

Figure 3 – Rubber Bulk Modulus values [4]

For the example runflat used in this report, a bulk modulus value of 1.5 MPa is used.

4.0 COMPRESSION CALCULAION

The geometry in Figure 1 is simplified to that shown in figure 4 for easy calculation of the contact/compression area of the runflat. With the assumption of constant width, as given in Table 1, the area is easily determined from the length compression length, x , given by $h(2r-h) = \left(\frac{x}{2}\right)^2$ in [5].

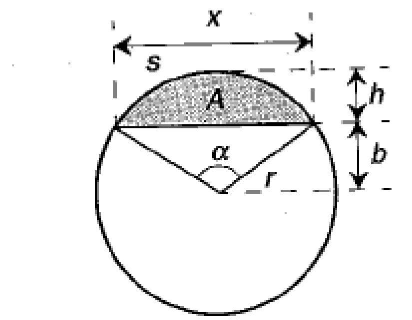

Figure 4 – Runflat Compression – Side View [5]

Solving for, x , gives $2\sqrt{h(2r-h)}$.

5.0 SPREADSHEET CALCULATION

Having assembled the relevant dimensional and material properties that characterize the runflat, a spreadsheet is used to calculate the compression forces generated upon impact. Figure 5 details these calculations.

Rubber Bulk Modulus	1.5	MPa			
Runflat Width	2.6	inches			
Runflat Radius	11.9055				
	Deflection	**Contact Length**	**Contact Area**	**Force**	**Rate**
	h	x	A	F	R
	inches	inches	inches^2	pounds	pounds/in
	0.10	3.08	8.01	1742.04	
	0.20	4.35	11.30	2458.41	7163.75
	0.30	5.31	13.81	3004.54	5461.33
	0.40	6.12	15.91	3461.96	4574.19
	0.50	6.83	17.75	3862.32	4003.54
	0.60	7.46	19.41	4221.87	3595.54
	0.70	8.04	20.92	4550.31	3284.37
	0.80	8.58	22.31	4853.95	3036.40
	0.90	9.08	23.61	5137.19	2832.42
	1.00	9.55	24.84	5403.24	2660.53
	6.00	20.68	53.76	11695.05	1258.36
	7.00	21.70	56.41	12272.36	577.31
	8.00	22.49	58.48	12723.51	451.15
	9.00	23.09	60.04	13061.58	338.07
	10.00	23.50	61.11	13295.20	233.62
	NOTE: 1 MPa = 145.04 psi				

Figure 5 – Force/Rate Spreadsheet

Depending on the cells, usually denoted B3, B8:B22, etc. in Microsoft Excel, the following formulas are used with the variables replaced by the appropriate cell ranges.

Table 2 – Spreadsheet Formulas

B	Bulk Modulus	**User Specified**
w	Runflat Width	**User Specified**
r	Runflat Radius	**User Specified**
h	Deflection	**User Specified Range**
x	Contact Length	=2*SQRT(h*(2*r-h))
A	Contact Area	=x*w
F	Force	=B*A*145.04
R	Rate (dF/dh)	=(F2-F1)/(h2-h1)

It is important to notice the decreasing rate of change of the force with respect to the deflection in Figure 5. Because of the circular geometry, as shown in Figure 4, most of the change in the contact area is due to the contact length, x, at small deflections, h. As the deflections, h, increase the contact length approaches the diameter of the circular structure much slower. However, the effective bulk modulus of the material will most likely increase due to the localized compression---this is not accounted for but would in effect increase the stiffness. Based on these observations, the stiffness's at the smallest deflections are taken to be the effective stiffness of the runflat.

This rate of change of the force with respect to the deflection is particularly important from a modeling viewpoint. Generally, the tire vertical force versus deflection is specified as a curve that is used as a table lookup that is interpolated from to provide effective tire forces. By defining the runflat stiffness as a rate (slope) to extrapolate values outside of the defined tire stiffness region makes it simple to model runflat effects with a single stiffness value.

Including the effects of runflat stiffness in tire models is particularly important for simulating vehicle dynamics in off-road environments where the tire deflections will periodically enter the runflat region.

6.0 CONTACT REGION

Determination of the beginning of the runflat contact region caused by deflection of the tire must consider the tire dimensions as outlined in Table 3 below and runflat dimensions as outlined in Table 1.

Table 3 – Tire Dimensions (inches) [6]

Undeflected Diameter	36.6
Tread Depth	0.59
Undertread Thickness	0.27
Carcass Thickness (estimated)	1.00*

From [6] the calculation is defined in Table 4.

Table 4 – Runflat Contact Tire Deflection

Tire Outer Radius	18.30
Tread Depth	-0.59
Undertread Thickness	-0.27
Carcass Thickness	-1.00
Runflat Outer Radius	-11.91
Runflat Contact Deflection	4.53

7.0 RESULTS

Using various bulk modulus values for the example runflat defined in Table 1 and the spreadsheet outlined in section 5.0, Figure 6 plots the effect bulk modulus has on runflat stiffness. Averaging the lowest two rates at 1 and 1.5 MPa, a runflat stiffness of approximately 6,000 pounds per inch is defined. It should be noted that a somewhat higher stiffness, 10,000 pounds per inch, was used in [7] but no real justification, as attempted here, was provided.

From Table 4, after 4.53 inches of tire deflection the runflat will be contacted.

It should be noted that varying the runflat and tire dimensions in Table 1 and Table 3, respectively, will change the runflat stiffness and runflat contact deflection results provided in this report.

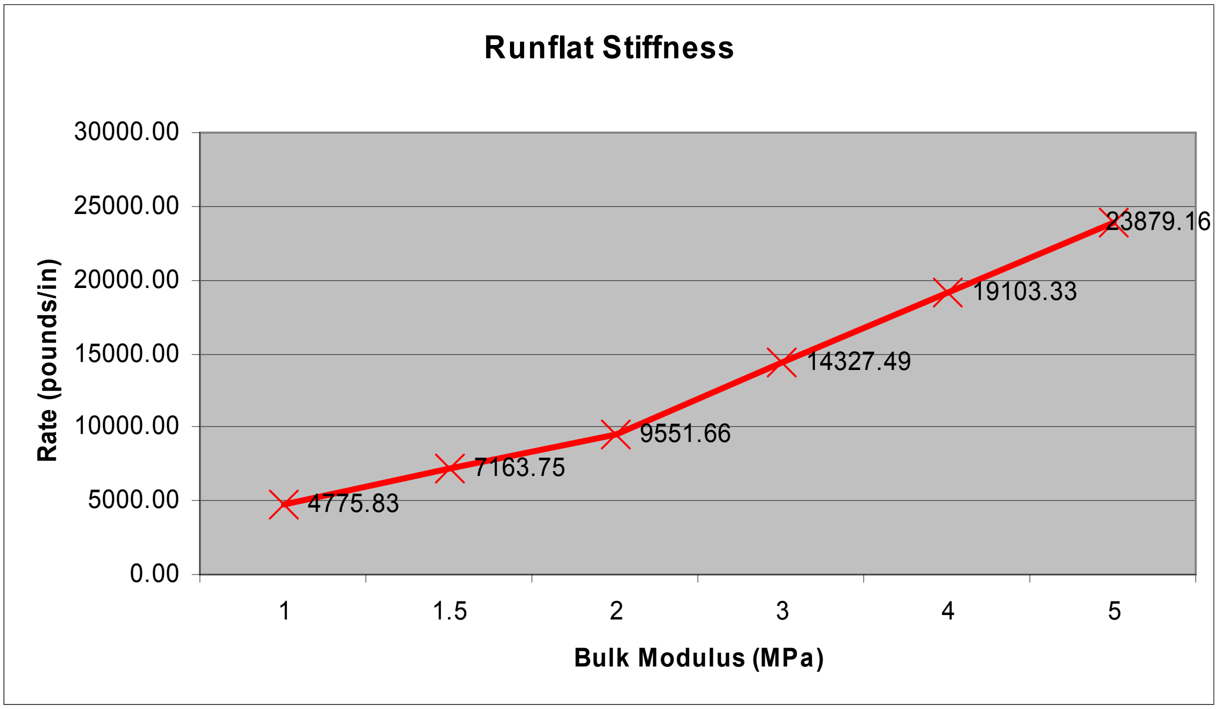

Figure 6 – Stiffness vs. Bulk Modulus

8.0 SUMMARY

For the runlfat and tire dimensions provided, the estimated runflat stiffness is 6,000 pounds per inch and will be contacted after 4.53 inches of tire deflection.

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[7] James Aardema, Failure Analysis of the Lower Rear Ball Joint on the High-Mobility Multipurpose Wheeled Vehicle (HMMWV), TR 13337. August 1988.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

RDECOM – U.S. Army Research, Development and Engineering Center
TACOM - U.S. Army Tank-automotive and Armaments Command
TARDEC - TACOM Research, Development and Engineering Center

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